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Anmelder/Applicant(s)/Demandeur(s):

Koninklijke Philips Electronics N.V.
Groenewoudseweg 1
5621 BA Eindhoven
PAYS-BAS

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Freezing point depression for electrowetting elements

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Freezing point depression for electrowetting elements

Introduction

In electrowetting-based optical elements the temperature range in which the element can be used depends greatly on the freezing point of the liquids used. For mobile phone applications temperatures well below 0°C are to be expected. Therefore, the element should still work at temperatures of approximately -20°C.

Technical problem

The known aqueous solutions and some non-conducting liquids do not meet this requirement. The problem is to find a way to lower the freezing point of the liquid below -20°C, while at the same time maintaining the requirements for electrowetting lenses.

Solution

A known method to lower the freezing point of a liquid is to dissolve a salt in the liquid. A low concentration (0.1 M) of salt is already used to make the aqueous solution electrically conducting, but this hardly affects the freezing point. Larger concentrations (in the range of 3 M or more, depending on the salt) are needed to effect a sufficient drop in the freezing point. However, it is by far not clear that the electrowetting properties required for the lens are not affected by this action. For instance, by dissolving too much salt in the liquid the density of the liquid increases, and, as a result, the required density matching between the conductive and non-conductive liquids can not always be met to make it insensitive to gravitational forces. Furthermore, not all salts give rise to a sufficient lowering of the freezing point. This can be due to the fact that not enough of the salt stays dissolved at low temperatures, or because some salts form highly viscous solutions at low temperatures. Also, dissolving salt in a liquid may give rise to a change in refractive index. For instance, the refractive index of water increases when KCl is added. As a result the refractive index difference between this liquid and the non-conductive liquid decreases (usually, the non-conducting liquid has a higher refractive index then the conducting liquid), leading to an undesirable decrease in optical power range of an electrowetting lens.

(1) We propose to dissolve an appropriate amount of salt, such as NaCl, LiCl, etc, in the conducting liquid, thereby lowering the freezing point by freezing point depression to approximately -20°C. The theoretical freezing point depression reached by a given amount of salt in moles of ions per kilogram of liquid can be determined from formula (1):

$$\Delta T_f = K_f c_m$$

Formula (1): Freezing point depression, with ΔT_f the change in freezing point, K_f the freezing point depression constant and c_m the molar concentration of ions of the solution.

In table (1) some freezing point depression constants are given:

Solvent	Formula	Melting Point (°C)	K_f(°C/m)	c_m for -20°C
Water	H_2O	0.000	1.858	10.8
Acetic acid	$HC_2H_3O_2$	16.60	3.59	10.2
Benzene	C_6H_6	5.455	5.065	5.0
Camphor	$C_{10}H_{16}O$	179.5	40	5.0
Cyclohexane	C_6H_{12}	6.55	20.0	1.3

Table (1): Freezing point depression constants for selected liquids

Note that in table 1 c_m is the molar concentration of the ions in the solution to obtain a freezing point below -20°C. Since each salt molecule gives rise to at least two ions, the required amount of salt dissolved in the liquid is smaller than c_m by at least a factor of two. For instance for LiCl 5.4 M is required to lower the freezing point of water to -20°C.

(2) To keep the refractive index low for the conductive liquid, the ions should have a low molecular weight, such as lithium, ammonium and fluor. However, some fluorine salts, e.g. KF, $NaBF_4$, do not give the desired freezing point depression. Chlorine salts, such as LiCl, are a good alternative.
Preferably, the atomic weight of the atoms should be below 40 u.

(3) For inverted lenses (the conducting liquid has a higher refractive index then the non-conducting liquid) however, an increase in the refractive index of the conducting liquid is desired. Dissolving for instance Cs_2WO_4 in water gives n=1.482. When combined with a low refractive index non-conducting liquid, e.g. silicon oil, n=1.37, a lens with considerable optical power can be made.

(4) To allow density matching with the non-conductive liquid the same applies as with mark (2)

Embodiment
An example of a conducting solution with a freezing point below -20°C is a solution of 5.4 m LiCl in water.

Application
Conducting solutions with appropriate amounts of dissolved salts can be used in electrowetting elements, in particular electrowetting lenses, diaphragms, gratings, filters, beam deflectors and displays. Examples of such elements have been disclosed in international patent application no. IB03/00222 (PH-NL020163), European patent applications no. 02078939.2 (PH-NL020947), no. 02080387.0 (PH-NL021251) and no. 02080060.3 (PH-NL021187). The elements are particularly suitable for use in devices operating in low temperature situations, e.g. in mobile phones, optical scanning devices or cameras.

Claims:

1 An optical element comprising a fluid chamber including a first body of a first fluid and a second body of a second fluid, the two bodies being separated by a meniscus, the position and/or shape of which is electrically controllable, the first fluid being electrically conducting and the second fluid being electrically non-conducting, characterized in that the first fluid comprises a dissolved salt for lowering the freezing point of the first fluid.

2 An optical element according to Claim 1, wherein the salt is a light salt.

3 An optical element according to Claim 2, wherein the salt is a chlorine salt.

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